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Analysis of Jordan's industrial energy intensity and potential mitigations of energy and GHGs emissions

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ABSTRACT

This paper aims to identify the main drivers behind energy intensity changes of the Jordanian industrial sector and to introduce the impact of energy efficient measures within the Jordanian industrial sector. To achieve these objectives, two empirical models were developed for electricity and fuel intensities, respectively of the Jordanian industrial sector based on multivariate linear regression. It was found that the structural effect, electricity prices, capacity utilizations and number of employees are the most important variables that affect changes of electricity intensity while fuel prices, capacity utilizations and number of employees factors are the most important variables that affect fuel intensity. The results show that multivariate linear regression model can be used adequately to simulate industrial energy intensity with very high coefficient of determination. Also, the impact of implementing energy saving technologies, such as use of high efficiency motors (HEMs), optimize motor size, variable speed drives (VSDs), bare steam pipes insulations, steam leak prevention, steam traps repair, and adjustment of boiler air/fuel ratio were investigated and found to be significant. Without such basic energy conservation and management programs, energy consumptions and associated GHG emissions for the industrial sector are predicted to rise by 25% and 23%, respectively in the year 2021. If these measures are implemented on a gradual basis, over the next decade, industrial energy consumption is predicted to rise at a lower rate, reaching 11.9% for same period with low/no cost actions. This would yield an estimated annual emission reductions of 570×10^3 t. In addition, the total installed capacity cost savings is estimated to be around 81.9 million US$ by year 2021.

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1. Introduction

The study of the trends in energy intensity, defined in this paper as the energy input relative to the gross output of the Jordanian industrial sector, is very useful in the areas of energy analysis, environmental issues and policy evaluation since it gives an indication of how efficiently the energy is being used rather than just analyzing energy consumption trends that does not give such indication. As an example, knowing that a plant consumed 10 GJ in year 1 and 15 GJ in year 2 will not give us an idea of how efficient the plant in using the energy from one year to another, however, adding that the plant produced 1000 units in year 1 and 2000 units in year 2, we can judge that the plant used the energy in more efficient way in year 2 (the energy intensity is 10 MJ/unit in year 1 while 7.5 MJ/unit in year 2).

Despite this, wide ranges of studies in terms of their objectives, scope, assumptions and applications have been conducted to model and forecast energy consumption that range from complex model [1], that consists of several modules that interact with each other through an integration module, to a simple one based on time series technique [2], that consists of only a single equation model of industrial energy consumption; a survey of such models can be found in [3]. Paradoxically, little work has been done on energy intensity modeling [4]. In this paper, two models for fuel and electricity intensities of the Jordanian industrial sector, respectively are developed to quantify the historical underlying effects of energy intensity changes. Such models would help energy policy planners in understanding the implications of changes in the exogenous variables when the underlying relationships are fairly stable. The establishment of such models will form the first objective of this paper.

Energy is a vital input for social and economic development of a nation. Global population and energy needs are increasing day by day. It has been found that total world population rose from 6085 million in 2000 to 6849 million in 2010 and projected to reach 9346 million in 2050. It is also expected that the average increase in population growth between 2010 and 2020 is projected to be 10.74%. Thus, this issue must be addressed by the international community to overcome any shortage of energy resources in future [5].

Jordan is a small country in the north-western corner of Asia, lies in one of the most volatile areas in the world, i.e., the Middle East region. Unfortunately, unlike other Arab neighboring countries, it is a non-oil producing country with limited natural resources and minerals. Its economy was based primarily on agriculture and farming; however, in recent decades the importance of the agricultural sector has declined both in terms of its contribution to the national income and as main source of employment. The country has become more dependent on services and manufacturing sectors as well as upon tourism and transport activities. As other developing Asian countries, it has a rapid population growth of about 2.2% [6]. The population and economic growth as well as development that Jordan experienced since its independence, in mid-1950s, implied a gradual shift of the population from rural to urban areas. Thus, urban population has increased from about 70%, in 1990, to 82%, in 2009 [7], of total population, putting the kingdom among the most urbanized countries in Asia. A major structural phenomenon of urbanization is the increasing shift of large proportions of the population to modern centers with relatively high incomes, requiring higher rates of energy consumption to sustain the new life.

The industrial sector in Jordan was probably affected the most by the economic and technological changes that the country has witnessed during the past three decades. For example, in 1985, there were about 4546 industrial facilities and workshops, and 43,313 employees. Two and half decades later, the industrial sector has grown to include about 14, 923 facilities and employed approximately 200 thousand workers, most of them are Jordanians. Such enormous increase in the number of facilities and produced products has contributed to an increase on energy demand. As in most developing countries, substantial energy losses exist in a large number of industries in Jordan. Reduction of such losses would improve energy efficiency significantly, which means less reliance on energy imports, and less CO_2 emissions. In order to support ongoing and future energy related research and policies, an energy consumption model based on time series technique is developed in this paper for the industrial sector. Such model has the advantage of being simple and capable of evaluating impacts of implementing energy saving strategies and technologies, such as use of high efficiency motors (HEMs), optimize motor size, variable speed drives (VSDs), bare steam pipes insulations, steam leak prevention, steam traps repair, and adjustment of boiler air/fuel ratio, on future energy consumption and associated reduction in CO_2 emissions. This will form the second objective of this study.

2. Energy demand in Jordan

Jordan is poor in terms of recoverable energy sources, compared with neighboring Arab countries. Furthermore, its economy is fragile and depends heavily on the general situation within the region, which is considered politically instable and hostile for the last six decades. The national energy demand has grown rapidly and it is expected to continue so in the near future. The continuous growth in energy demand has led to the increased dependence on imported crude oil, refined products and natural gas. At present, the country is importing crude oil and natural gas to sustain its present way of life. This leads to a significant hard-currency drain in the economy, with an annual oil bill exceeding 3 billion US$ [7]. Such high value represented approximately 12% of the GDP, in 2009, and 42% of domestic exports and about 19% of total imports into the country. It is extremely difficult for a country such as Jordan to continue spending nearly half of its national income from exporting domestic commodities just to import needed oil for social and economic development. Equally important is the security of supply of energy needs. As recently as the mid-1980s, Jordan was totally dependent on imported crude oil from Saudi Arabia through a pipeline system, i.e., the Tapline which connects oil field in eastern Saudi Arabia to Zahrani in northern Lebanon through Jordan and Syria. Late in 1984, it began to import crude and fuel oil, as a counter-purchase agreement, from Iraq. This enabled Jordan to achieve an important diversification in both the type and source of imported energy. Since the 2nd Gulf crisis, during 1990–1991, Jordan has become totally dependent on crude oil and some refined products, which imported solely from Iraq by road trucks with an average round-trip of about 1500 km. Again, as a result of the 3rd Gulf War, the country diverted its crude and fuel oil imports from Iraq

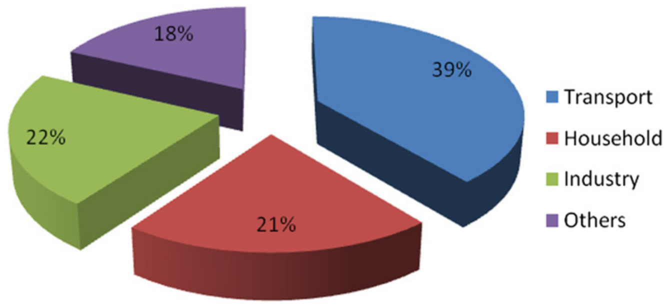

Fig. 1. Percentage ratios of the final energy sectoral distribution in 2009.

to Saudi Arabia and Kuwait. Imported crude oil is delivered at Aqaba port, and then transported by road trucks to the oil refinery nearby Zarqa with an average round trip of about 800 km. During the Gulf wars, the loss of supplies from Saudi Arabia and/or Iraq effectively eliminated Jordan's crude oil reserves and security of supply. Thus, the government was forced to acquire and put into service an old oil tanker, berthed in the port of Aqaba, to serve as a back-up emergency store of crude oil. This is unacceptable as a permanent solution, but it indicates the political uncertainties and the lack of capital to correct such a situation. Crude oil security for the next few decades would be improved by constructing a new pipeline from Saudi Arabia or Iraq, as well as expanding the current storage capacity. Besides the conventional ways to address energy problem through supply augmentation, many measures should be considered in order to enhance efficiency of energy utilization and reduce demand in all sectors, including industry.

The demand for primary energy in 2009 was about 7.739 million tons of oil equivalent (toe), compared with 2.4 million toe in 1982. Transport sector is the largest single consumer, followed by households and industry (see Fig. 1). In Fig. 1, others include commercial and services, government and agricultural sectors. The current pattern of sectoral energy consumption is most likely to remain unchanged in the future if current polices and strategies are not altered. It is expected that annual energy demand will increase at relatively high rates posing more pressure on the national economy.

3. Industrial firms in Jordan

Industry is a main contributor to Jordan's economy, accounting for approximately 22.5% of Gross Domestic Product (GDP) in 2009, about 90% of national exports and employing 15% of the country's labor force [8]. Jordan's industrial sector is composed mainly of "mining and Quarrying" and "manufacturing". The mining and quarrying mainly includes potash and phosphate, and accounted to 3.3% of GDP in 2009, while manufacturing contributed to 19.2% of Jordanian GDP in 2009.

The manufacturing sector has a wide range of activities. The national classification of industrial sectors has been determined by Jordan cabinet on August 13, 2005 to cover all industrial enterprises operating in one activity. Thus, the industrial activities are grouped according to the following eleven sectors: leather and garments, therapeutics and medical, chemical and cosmetics, plastic and rubber, engineering and electrical industries, furniture and wooden, construction, food, paper, cartoon and stationeries, and mining.

Additionally, in order to obtain a comprehensive representation of the enterprises working in industries, the micro-enterprises are considered as the twelfth sector. In 2009, there were approximately 14,923 enterprises operating in industry, employing almost 198,876 employees, and having total registered capital of 4100 million US dollars. Industrial Enterprises with 10 or more Jordanian employees and registered capital of $ US 42,000 or more constitute 13% of the total number of enterprises operating in Jordan industrial sector, employing 79% of the total industry labor force, and accounting for 94% of industrial registered capital in 2009 while the "micro-enterprises" constitute 87% of the total number of enterprises operating in Jordan industrial sector, employing 21% of the total industry labor force, and accounting for 6% of industrial registered capital in 2008 [8].

4. Methodology

Energy modeling is a subject of widespread current interest among engineers and scientists concerned with problems of energy production and consumption. Energy modeling in some areas of application is now capable of making useful contributions to planning and policy formulation. Depending on the available data, several models have been proposed to model industrial energy consumption that can be classified into two groups: econometric and artificial intelligence approaches. The first group includes multiple linear regression [2], and time series [4] while the second group includes artificial neural network [9], and fuzzy theory [10].

In this paper, and according to the available data and the purposes hoped from this study, the general model approach that is based on multivariate regression analysis will be utilized to achieve the first objective of this study. This method has proven to be an effective tool to analyze and identify different factors that affect fuel and electricity consumptions in different sectors such as industrial one [2–4].

It should be noted here that the regression method used to achieve the first objective of this study is generally valid over the region of regressor variables contained in the observed data. Montgomery and Runger [11] have discussed dangers of extrapolation when using a regression model for prediction; therefore, this study uses a technique based on time series analysis to predict the future energy demand and develops a mathematical approach to analyze and evaluate the impacts of different energy efficiency measures on the fuel and electricity consumptions in the Jordanian industiral sector; this will achieve the second objective of this study.

4.1. The multivariate regression model

Regression analysis is a statistical technique that involves exploring the relationships between two or more variables through building a model equation that relates the response (variable of interest) to a set of predictor variables. The starting point of this analysis is to define the response variable and the potential factors (predictor variables) that are important to explain the response's behavior. In our analysis, energy intensity is the response variable. There are some factors that can be considered to be significant for determining the energy intensity of industrial sector. In this study, the following parameters were treated as causal variables: the structural effect (G_I/G_N), electricity cost ($E\$$), fuel cost ($F\$$), capacity utilization (CU), and number of employees (EM). Eqs. 1 and 2 present the suggested multivariate linear regression models for fuel (FI) and electricity (EI) intensities, respectively.

$$(FI)_t = \mu_0 + \mu_{I,N}\left(\frac{G_I}{G_N}\right)_t + \mu_2(E\$)_t + \mu_3(F\$)_t + \mu_4(CU)_t + \mu_5(EM)_t + \varepsilon_t \quad (1)$$

$$(EI)_t = \mu_0 + \mu_{I,N}\left(\frac{G_I}{G_N}\right)_t + \mu_2(E\$)_t + \mu_3(F\$)_t + \mu_4(CU)_t + \mu_5(EM)_t + \varepsilon_t \quad (2)$$

Each of these variables is explained briefly hereafter, including reasons for their use in the proposed model:

(a) Structural effect (G_I/G_N): at a given level of output, as the demand changes towards more energy-intensive industries, total energy use rises. In contrast, if there is a shift towards less energy-intensive industries, total energy use decreases. To incorporate this effect in the regression model, the manufacturing sector is disaggregated into two clusters: intensive and non intensive clusters and the gross output ratio between them is included as a variable in the regression model. The energy intensity is expected to rise when these ratios increase, and vice versa, and therefore the coefficients (μ's) of these variables are expected to be positive.
(b) Electricity unit cost (E\$): When electricity tariff increases, the industry is expected to respond by employing more efficient processes and appliances, thus, rates of electricity consumption would be reduced. The coefficient sign of this variable is expected to be negative.
(c) Fuel unit price (F\$): Diesel and heavy fuel oil (HFO) are the most common substitutes for electricity in various industries [12]. It is expected that when unit price of diesel and HFO increased, the industry will respond by switching to electricity or other sources, such as diesel and HFO, and vice versa. The weighted average of diesel and HFO prices are included in the model. The coefficient sign of this variable is expected to be positive.
(d) Capacity utilization: This variable is a clear indicator on how efficient does the industry uses its resources including energy. As capacity utilization increases, then the industry uses its resources more efficiently. The coefficient sign of this variable is expected to be negative.
(e) Number of employees: This variable can be viewed from two different perspectives. To some degree, technology has replaced human labor in all industries, and therefore energy consumption may increase due to mechanization and automation, as opposed to human labor. On the other hand, each employee requires additional energy in the form of space cooling and/or heating, domestic hot water, lighting, etc., and thus energy consumption could decrease as machines replace human labor. Therefore, the coefficient's sign of this variable is undetermined.

Historical data from year 1985 to 2009 is utilized to build two regression models for the Jordanian industrial sector, one for fuel and another one for electricity intensities, respectively. The Minitab software package was used to quantify and test the significance of variables shown in Eqs. (1) and (2).

4.2. Evaluating savings from introducing efficiency measures

The following analysis aims to evaluate electricity and fuel savings, demand reduction, installed capacity savings, and environmental impact as consequences of implementing efficient practices, i.e., use of high efficiency motors (HEMs), optimize motor size, variable speed drives (VSDs), bare steam pipes insulations, steam leak prevention, steam traps repair, and adjustment of boiler air/fuel ratio in the Jordanian industrial sector.

4.2.1. Energy consumption savings

In order to quantitatively examine potential benefits from introducing high efficiency measures into the Jordanian industrial sector, five different scenarios are suggested:

- Scenario A: The situation will remain unchanged during the study period.
- Scenario B: The high efficiency measures will take a constant fully share of the new industries from 2012 until 2021.
- Scenario C: The high efficiency measures will take a constant share of 50% of the new industries from 2012 until 2021.
- Scenario D: The share of high efficiency measures will linearly increase to 100% of the new industries from 2012 until 2021.
- Scenario E: The share of high efficiency measures will linearly increase to 50% of the new industries from 2012 until 2021.

The suggested shares for scenario B and C are justified by the continuously increasing prices of energy Jordan witnessed recently. Scenarios D and E assume a more gradual and conservative approach in introducing high efficiency measures to the Jordanian market. For all five scenarios the following assumptions are made:

- The share of diesel and HFO will remain constant over the projected period.
- Electricity cost is about 0.06 JD/kW h (0.085 \$/kW h) based on weighted average of all industries according to the new tariff adopted by the government as in July, 2011.
- Installed capacity cost (infrastructure cost to generate electricity) is taken as an average of about 800 JD/kW installed (i.e., 1128 \$/kW installed).
- Duration of study will be taken as ten years. Practices prior to the period of study will gradually convert to the proposed practices. This conversion is assumed to be uniform along the duration of the study (one tenth of the energy will be converted each year). The share penetration will be taken as assumed for the five previous scenarios regarding the new industries.
- Cost savings will be provided in U.S. dollars, assuming a parity of \$1.41 to one Jordanian Dinar (JD), given recent currency exchange rates.

To evaluate the potential savings at period t (ES_t) for scenarios B and C, the following model is proposed:

$$(ES)_t = SF \times CP \times MS \times \left[\left(\frac{EE_0 \times t}{T}\right) + (EE_t - EE_0)\right], \tag{3}$$

In Eq. (3), SF represents the saving factor resulting from introducing the end-use efficiency measure, CP the energy coverage percentage of the end-use within the industrial sector, MS the proposed market share of the end-use efficiency measure, EE_0 the energy consumption of the industrial sector at the base year 0 (2011 in this study), EE_t the predicted energy consumption of the industrial sector for period t, and T is the study period length (in this study 10 years, from 2012 to 2021).

Eq. (3) can be rewritten as:

$$(ES)_t = SF \times CP \times \begin{bmatrix} MS\left(\frac{EE_0}{T}\right)_1 + \ldots\ldots + MS\left(\frac{EE_0}{T}\right)_t + MS(EE_t - EE_{t-1}) \\ + MS(EE_{t-1} - EE_{t-2}) \ldots + MS(EE_1 - EE_0) \end{bmatrix}, \tag{4}$$

Or more simply,

$$(ES)_t = SF \times CP \times \left[\sum_{i=1}^{t} MS\left(\frac{E_0}{T}\right)_i + \sum_{i=1}^{t} MS(E_i - E_{i-1}).\right], \tag{5}$$

However, this model assumes that both the uniform converted portion of the base energy consumption as well as the increase in energy consumption over the base year of the Jordanian industrial sector would be at the assumed market share of energy measure. However, to be conservative, this share will be assumed to be taken place linearly during the study period (scenarios D and E). To do this, the model becomes:

$$(ES)_t = SF \times CP \times \left[\sum_{i=1}^{t} ((\frac{i}{T})MS\left(\frac{EE_0}{T}\right)_i) + \sum_{i=1}^{t} \left(\left(\frac{i}{T}\right)MS(EE_i - EE_{i-1}).\right)\right], \quad 1 \le t \le T \tag{6}$$

4.2.2. Installed capacity savings

Demand savings will result from using electricity savings strategies, with smaller capacities compared to existing large and inefficient conventional equipments, which would reduce the installed capacity within the industrial sector and consequently lower capacity loads per unit of time inevitable. Therefore, utilities will most probably reduce future investments required for expansion projects starting from new power stations down to distribution networks due to expected lower rates of growth. The annual installed capacity savings, ICS_t, can be estimated as follows:

$$ICS_t = MDS_t \times ICC \tag{7}$$

where *ICC* is the installed capacity cost and is estimated to be 1126 US\$/kW installed, based on past power generation projects in Jordan [3], and *MDS* the annual demand savings and can be estimated as:

$$MDS_t = \frac{EES_t}{AOH}, \tag{8}$$

where *AOH* is annual operation hours (from the survey, it is estimated as 5840 h).

4.2.3. Environmental impact

Introducing efficiency measure practices will not only affect electricity and fuel consumptions but also negative environmental impacts (e.g., gaseous emissions such as particulate matter, nitrogen oxides, sulfur oxides and greenhouse gases) of conventional power generation units and the end-uses of the industries. In this paper, only greenhouse gas emissions, represented by carbon dioxide, will be evaluated as a result of employing efficient practices. The projected reduction in CO_2 emissions can be calculated based on direct relationship between electricity and fuel consumptions and CO_2 emissions: higher rate of consumption means more CO_2 to the atmosphere. Specific CO_2 emission coefficient (0.462 kg CO_2/kW h) is taken as weighted average of all power plants in Jordan during last year, i.e., year 2011. Also, the specific CO_2 emission coefficient is taken as 0.073 kg CO_2/MJ as weighted average of all combustible fuel used in the Jordanian industrial sector [2].

4.3. Energy-end use model

In order to quantify the energy savings from introducing energy savings strategies, the distribution of input energy among different end uses of the Jordanian industrial sector should be known (this refers to *CP* in Eq. (3)–(6)). Such detailed data and information are unavailable in Jordan not only for the industrial sector but also for most of Jordanian sectors. Since the collection and analysis of such data on a national scale is a costly process, a survey of a representative sample of 800 industrial facilities was conducted. This survey was aimed at collecting relevant data that are necessary to complete this study, and to gain further insights into fuel and electrical energy consumption characteristics. The questionnaires covered the following aspects:

- Types of lighting lamps, the power and working hours and the quantity used for each type.
- Types of motors, the power and working hours and the quantity used for each type.
- Types of compressors, the power and working hours and the quantity used for each type.
- Types of boilers, the fuel type and consumption, the steam and feed water quantities, the steam and feed water temperatures, and the quantity used for each type.
- Types of furnaces, the fuel type and consumption, the stack temperature, and the quantity used for each type.
- Types of pump, the power and working hours and the quantity used for each type.
- Type of cooling systems, the process temperature, the power and working hours and the quantity used for each type.

To ensure the quality of such survey, each facility was given a tutorial explanation, either by a site visit or/and over the phone, to explain how to collect and record the required data correctly and efficiently. Only 180 correctly completed questionnaires were included in the analysis. The survey was conducted during 2008–2011 years. Table 1 shows the type and numbers of facilities involved in this study.

4.4. Time series analysis

In order to use the developed models (Eqs. (3)–(8)), the predicted future fuel and electricity consumptions of the industrial sector are required. This data can be generated using a forecasting tool based on time series technique. The analysis of historical fuel and electricity consumptions of the industrial sector over the period 1985–2009 shows an evident long-run trend similar to that seen in Fig. 2. The double exponential smoothing forecasting time series method is recommended in such situations [13]. The double exponential forecasting equation is as follows [13,14]:

$$F_{t+m} = a_t + b_t m \tag{9}$$

where F_{t+m} is the forecast after *m* number of periods ahead, *m* the number of periods ahead to be forecast, a_t the forecasted intercept, and b_t the forecasted slope.

The intercept a_t and the slope b_t are estimated as follows:

$$a_t = 2S'_t - S''_t \tag{10}$$

$$b_t = \frac{\alpha}{1-\alpha}(S'_t - S''_t) \tag{11}$$

Table 1
Number of completed surveys.

Subsector	No. of completed surveys
Textile	22
Pharmaceutical	17
Chemical	34
Plastic	36
Mining and quarrying	12
Food	37
Paper	22
Total	180

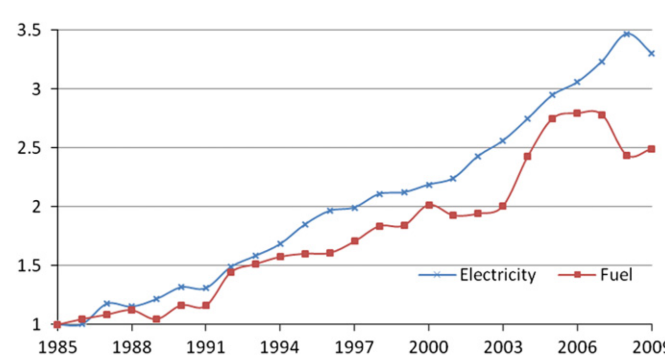

Fig. 2. Indices values of historical fuel and electricity consumptions of the Jordanian industrial sector.

$$0 \le \alpha < 1 \tag{12}$$

where α is the smoothing constant used to weight current and past observations, and S'_t and S''_t the single and double exponential smoothing values, respectively for time t. These S'_t and S''_t values are calculated as follows:

$$S'_t = \alpha X_t + (1-\alpha)S'_{t-1} \tag{13}$$

$$S''_t = \alpha S'_t + (1-\alpha)S''_{t-1} \tag{14}$$

The higher α is, the more weight is given to the most recent observations. Before running the analysis, α should be selected. The forecasts for electricity and fuel consumptions are calculated using different α's, and the α that gives a small mean square error for the forecasts and shows an expected future growth is chosen. In addition to choosing appropriate α, values of S'_{t-1} and S''_{t-1} must be assumed when $t=1$ since no such values exist for this period. This problem can be solved by assuming that both values are equal to the initial historical data since α values for both fuel and electricity consumptions are larger than zero and the number of data points is more than 20 [13,14].

5. Data sources

The energy intensity in the regression model is based on the ratio of energy input to gross output. Energy will be used as a general word to refer either to fuel or electrical energy. Gross output has been deflated and expressed in 2006 constant dollars, and so gross output refers to 2006 constant dollar gross output.

Historical data, during the period 1985–2009, were utilized to develop the multivariate linear regression model of fuel and electricity intensities in the Jordanian industrial sector. The following data sources were utilized based on available information and consultation with highly qualified experts and consultants working in concerned governmental and private institutions, these are:

- Fuel and electricity consumption, diesel and HFO retail prices were obtained from the Ministry of Energy and Mineral Resources [15].
- Gross output and number of employees were obtained from Department of Statistics [16].
- Electricity unit prices were obtained from the electricity tariff [17,18].
- Energy intensive cluster includes mining and quarrying, textiles, papers, basic metals, and plastics. While non-energy-intensive cluster includes all other industries, mainly small and medium, in the industrial sector. Knowing this, the ratio between the gross outputs (G_I/G_N) of these two clusters can be determined.
- A change in the gross output from one year to another includes an increase (or decrease) in price resulting from inflation or deflation; such changes do not reflect a change in output. Therefore, before using estimates of the gross output as an output measure, they were adjusted for the effect of changes in price using the producer price index (as reported in year 2006) obtained from obtained from the Central Bank of Jordan [19].
- Since no accurate data is available regarding capacity utilization in most industrial sub-sectors in Jordan, a simple but reasonable approach was used to estimate the relative capacity utilization form one year to another in different industries. For a given industry, ratio of total gross output to number of facilities within the industrial sub-sector was calculated on yearly basis. The maximum ratio is taken as an indication of maximum capacity utilization and is given a value of one. The capacity utilization for other years were calculated relative to the maximum ratio obtained, i.e., by dividing the ratio obtained for a given year by the maximum ratio. The overall industrial sector capacity utilization was calculated as a weighted average of capacity utilization for all industries for a given year. Table 2 summarizes complete set of data used in this study.

Table 2
Data set for the Jordanian industrial sector fuel and electricity intensities models.

Year	EI (MJ/$)	FI (MJ/$)	G_I/G_N	E$ ($/TJ)	F$ ($/TJ)	CU (%)	EM
1985	2.00	7.99	0.31	10,638	2,494	40	43,313
1986	2.22	9.00	0.35	9,682	2,456	34	40,529
1987	2.35	9.47	0.38	8,780	2,244	30	41,824
1988	2.40	9.50	0.41	8,621	2,296	27	41,647
1989	2.42	9.60	0.45	8,294	2,820	26	48,791
1990	2.30	9.48	0.42	10,992	2,818	30	51,617
1991	2.30	9.62	0.38	11,025	2,828	32	57,434
1992	2.17	9.21	0.35	12,242	3,444	35	70,393
1993	2.10	9.00	0.30	12,254	3,565	45	71,413
1994	2.07	9.00	0.28	12,204	3,600	52	99,660
1995	2.08	8.36	0.29	12,152	3,644	55	103,176
1996	2.00	8.10	0.31	14,242	3,646	60	106,437
1997	2.01	8.00	0.32	14,218	3,648	63	108,219
1998	2.10	8.50	0.29	14,196	3,713	56	110,229
1999	1.99	8.30	0.31	14,217	3,720	60	116,061
2000	1.95	8.20	0.27	14,217	3,725	64	123,348
2001	1.94	8.30	0.28	14,241	4,096	65	130,296
2002	1.93	8.40	0.26	14,608	4,386	65	136,653
2003	1.90	8.20	0.25	14,992	4,870	74	143,010
2004	1.90	8.00	0.24	15,052	5,138	75	149,367
2005	1.88	7.90	0.23	15,560	8,373	77	157,980
2006	1.87	7.80	0.23	15,560	11,989	75	168,456
2007	1.86	7.70	0.22	15,560	11,989	76	179,861
2008	1.75	6.75	0.19	18,844	27,098	85	188,820
2009	1.70	5.58	0.18	18,844	14,386	100	198,876

Table 3
Regression summary outputs for electricity and fuel intensities models$^+$.

	Electricity intensity (MJ/$)[a]	Fuel intensity (MJ/$)[b]
Variable	Coefficient	
Intercept (MJ/$)	2.0583	11.0845
G_I/G_N	1.4323	—————————[c]
E$ ($/TJ)	−0.00002381	—————————[c]
F$ ($/TJ)	—————————[c]	−0.00006493
CU (%)	−0.005710	−0.08915
EM	0.00000181	0.00002494

[a] R^2=96.2%, and adjusted R^2=95.4%.
[b] R^2=92.4%, and adjusted R^2=91.3%.
[c] Variable is not significant at 0.05 p-value.

6. Results and discussions

6.1. Multivariate regression analysis results

A multivariate regression analysis software package, Minitab, is used to estimate the coefficients (μ's) associated with each variable shown in Eqs. (1) and (2), and to test their significance. This software tests also significance of the multivariate linear regression model using the ANalysis of VAriance (*ANOVA*), which is based on the least square method [11]. Using this technique, structural effect, electricity prices, capacity utilization, and number of employees are the most important variables that affect electricity intensity, while fuel prices, capacity utilizations, and number of employees are the most important variables for the fuel intensity case. Table 3 demonstrates the *ANOVA* analysis for

electricity and fuel intensities models, noting that variables included in models are significant since the *p-value* associated with each parameter is less than 0.05. In order to verify the multivariate linear regression models, its adequacy and performance should be checked:

- *Assumption validation*: The *ANOVA* tool used in the multivariate linear regression analysis to testify the validity and significance of the model is based on some assumptions, such as residuals having constant variance and being normally distributed. A graphical analysis of the residuals was carried out for each of the regression models to check the validity of such assumptions. As an example, Fig. 3(a and b) shows the residual versus fitted values, and the normal probability plot for the Jordanian electricity intensity model. The analysis demonstrates satisfactory results since residuals are contained within a horizontal band, i.e., the constant variance assumption is satisfied, and since the cumulative normal distribution is approximately a straight line, i.e., the normality assumption is also satisfied. Satisfactory results have been also demonstrated for fuel intensity model.
- *Outlier, leverage and influence points diagnosis* (*unusual points*): No outlier, leverage, and influential points were detected in any of the regression models.
- *Goodness of fit*: The model seems to reasonably represent the behavior of the data since the values of the coefficient of multiple determination (R^2) and adjusted R^2 statistics are very high as shown in Table 3. These are the most popular measures of goodness-of-fit.
- *Analysis of model coefficient signs*: All coefficients in all models have the expected signs, and their magnitudes seem to be reasonable.

From the preceding tests, one can conclude that the suggested model does not violate main assumptions and represent data accurately. The complete equations for electricity and fuel intensities models are:

$$\hat{(FI)}_t = 11.0845 - 0.00006493(F\$)_t - 0.08915(CU)_t + 0.00002494(EM)_t \quad (15)$$

$$\hat{(EI)}_t = 2.0583 + 1.4323\left(\frac{G_I}{G_N}\right)_t - 0.00002381(E\$)_t - 0.0571(CU)_t + 0.00000181(EM)_t \quad (16)$$

where $\hat{(FI)}_t$ is the estimated fuel intensity in year t (MJ/\$) and $\hat{(EI)}_t$ the estimated electricity intensity in year t (MJ/\$).

6.2. Energy end-use balance

In order to determine the energy savings and emissions reductions by implementing energy savings strategies, the proportion of energy consumed for each end-use process within the industry should be known. For each sub-sectors in Jordan and irrespective of the kind of industry or type of product considered, there are common primary end-uses: process steam, electricity for motors, electricity for cooling, and electricity for lighting and furnaces. For each industry considered in this research, the energy proportion of each end use will be determined. The energy balance defines different categories of energy input; electricity and fuel, and the energy allocated to different end-use processes (steam process, machine drive, process cooling, lighting, and furnaces).

For each end-use process, the energy consumption is calculated from the gathered data and the proportion of energy consumed for each end-use is then estimated by dividing the end-use energy consumption by the total firm energy consumption. The overall energy proportion for each end-use within the manufacturing sector is estimated as the overall weighted proportions of the end-use for all industries within the same subsector. Table 4 summarizes the electricity balance for each sub-sector as well as the overall Jordanian industrial sector. The share of process steam production has been found to be approximately 70% of the total fuel input to Jordanian industrial sector.

Table 4
Electricity balance of the Jordanian industries.

Sub-sector	Motors (%)	Cooling (%)	Lighting (%)	Furnaces (%)	Others (%)
Textile	58.9	20.5	19.3	0	1.9
Pharmaceutical	51.6	29.1	11.2	3.5	4.7
Chemical	71.5	15.7	5.6	2.2	5.0
Plastic	73.7	17.5	4.2	0	4.6
Mining and quarrying	70.5	7.3	3.1	16.9	2.2
Food	65.3	20.5	7.0	2.3	4.9
Paper	72.0	4.2	6.1	13.1	4.6
Over all sector	69.1	14.2	5.2	7.5	4.0

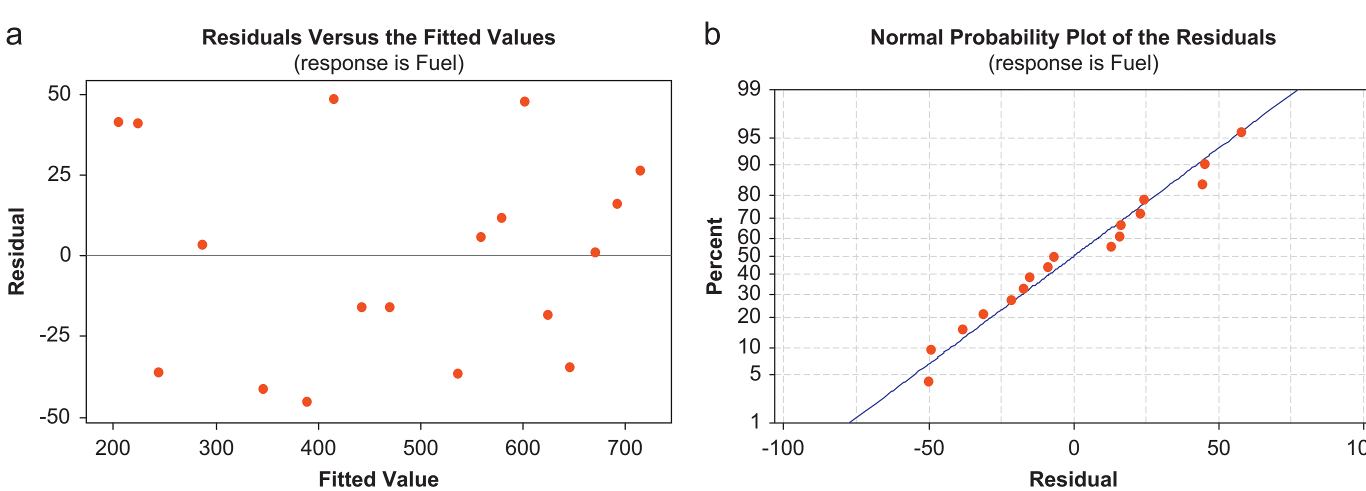

Fig. 3. (a) Residual versus fitted values and (b) normal probability plot, for the Jordanian industrial electricity intensity model.

6.3. Impacts of adopting energy efficiency strategy

Unfortunately, many processes are employed in different industries without sufficient technical understanding and training. Also, the common practice, in Jordan, to import used machinery, plants and even spare parts from Europe and far-east countries is not helpful. Hence, Jordan abounds with relatively inefficient equipment, especially in the industrial sector. Furthermore, there is also a lack of understanding on the management level, of the importance of energy thrift and environmental protection as well as the vulnerability of the economy to the availability of commercial energy resources at reasonable prices. Net energy and electricity savings as well as emissions reduction that efficient energy practices have over existing conditions can be one of important answers offered to alleviate the worsening energy crisis on one hand and to reduce CO_2 emission intensity on the other hand.

6.3.1. Energy efficiency improvements in motors

Electrical motors are main consumers of electricity, with an average share of about 69.1% of total electricity consumed in industry as shown in Table 4. Any improvement in the efficiency of these motors would result in enhanced productivity, reduced costs and better competitiveness, as well as healthier environment. In Jordan, high ratios of working factories and/or production lines were imported as second hand. Moreover, most of motor-driven systems are conventional motors and oversized with a clear mismatch between the optimal electric motor output and the driven system's load. Replacement of old conventional motors with high efficiency motors represents a great opportunity for improving the system's efficiency. However, this should go in parallel with installing modern control systems such as variable frequency drives (VFD) where applicable and feasible.

A common practice for many facilities in Jordan is to rewind an existing motor when it burns out rather than purchase a high efficiency replacement motor. However, a rewound motor is typically less efficient than a new model. The loss of efficiency is due to the age of the failed motor and degradation of its stator core during failure, or as a result of the rewind process. For smaller motors, the cost to rewind is a significant fraction of the cost of a new energy efficient motor, and the increased efficiency of the new motor may provide adequate energy (and thus cost) savings over the rewound motor to justify its purchase. Hours of operation and the usage factor of an existing motor will also help to determine which option (rewind or purchase new) appears most favorable.

Energy efficient motors are constructed with better bearings and windings than standard efficiency motors to reduce frictional and electrical resistance losses. Depending on the horsepower rating of a given energy efficient motor, operating efficiencies may be from 1% to 10% higher than the operating efficiencies of the existing motors. In general, the larger the motor, the smaller the efficiency increase.

Variable frequency drive (VFD) is a device that regulates the speed and rotational force, or output torque of mechanical equipment. Some examples of mechanical equipment that incorporate with VFD technology are pumps, fans, compressors and conveyors. There are many types of equipment currently in use that needs to be retrofitted because they are running inefficiently; however, manufactures are introducing VFDs technology to save the losses of mechanical equipment [20]. VFD increases efficiency by allowing motors to be operated at the ideal speed for every load condition. In many applications VFDs reduce motor electricity consumption by 30%–60%. In many commercial and industrial environments, the application of variable speed control is cost effective. Energy savings result from reduced power consumption by the motors. As the system power requirements are reduced, the power consumed by the equipment can be reduced by an amount significantly greater than can be achieved with the existing controls. For example, in the case of pumps, flow is often controlled (throttled) by valves, which increase the pump head and reduce the flow rate. Fan output is typically controlled by closing inlet vanes, which increase the pressure head and reduces the flow rate of air, but the power requirements change very little.

Another strategy to reduce electricity consumption of motors is to optimize motor size with load [21]. Motor systems are sometime oversized when designers incorporate extra capacity for growth and safety. Designers assume that it is a small premium to pay to insure that the system will be able to cope with maximum demand. Sometimes over sizing may be warranted but sometimes it leads to costly waste. Most motor efficiencies peak at around 75% load and drop off sharply below 40% load. To stay within a motor's optimal operating bounds, it should be sized to run at 50% or more of its rated load most of the time. This is especially true of smaller motors since there is a more rapid decline in efficiency when the load is less than 50%. An oversized motor (below 40% loading) will run at low efficiency and low power factor, thus increasing energy costs and resulting in added utility charges to pay for reactive current. It is often beneficial to replace existing motors with smaller, high-efficiency units.

From the survey, it has been found that the average efficiency for motors is around 70%, less than 4% of motors are equipped with VFDs, and the average load factor is around 50%. From these figures, significant savings can be achieved by adopting energy efficiency strategies discussed before. A conservative saving figure (15%) is assumed here to estimate both forecasted savings and future avoided emissions using Eqs. 3–8 as shown in Table 5. From this table, it can be seen that significant benefits at local and national levels could be achieved if electric-motor efficient practices are introduced and implemented gradually in Jordanian industries. It is deemed that Jordan's energy bill will be reduced and industrial facilities will also save money and hence improve their competitiveness locally and for export purposes. This would also release some of the scarce capital investment, which is urgently needed for the development and growth of other sectors of the national economy. Moreover, a guaranteed reduction in rates of emitted pollutants, including GHG emissions, from power plants will simultaneously be achieved, but without capital investments.

6.3.2. Energy efficiency improvements in boilers

The largest use of fuel in many facilities in Jordan is in boilers. Boilers generate steam which is then used to provide space heat, process heat, mechanical power, and possibly electricity. Since their energy use is so significant, boilers are a good place to start in looking for ways to reduce energy costs. All industrial facilities in Jordan use fossil fuel-fired boilers (either diesel or HFO) to produce steam or hot water for space heating or process heating. During the sites survey of all relevant facilities, it has been found that the following recommendations are relevant for the majority of visited facilities:

(a) Adjust air–fuel ratio: the air–fuel ratio for all facilities have been checked and the majorities have been found to be inappropriate. Adjusting the combustion system air-fuel ratio on the boiler as needed will reduce the amount of excess air passing through the boiler and thus improve the combustion efficiency of the boiler.
(b) Insulate pipes of steam network: measurements of uninsulated surfaces were taken during the site visits. Insulation of the condensate and steam pipes located in the plant will reduce heat losses and associated energy costs. A majority of

Table 5
Electricity savings and environmental impacts by implementing energy efficiency strategies in motors.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Scenario A	3227	3314	3401	3488	3575	3662	3749	3836	3923	4010	4097
Scenario B											
Electricity savings (GW h)		42	85	127	170	212	255	297	340	382	425
Cost savings (M$)		3.6	7.2	10.8	14.4	18.0	21.6	25.2	28.8	32.4	36.0
Installed capacity savings (M$)		8.2	16.4	24.6	32.7	40.9	49.1	57.3	65.5	73.7	81.9
Carbon dioxide reduction (10^6 kg)		20	39	59	78	98	118	137	157	177	196
Scenario C											
Electricity savings (GW h)		21	42	64	85	106	127	149	170	191	212
Cost Savings (M$)		1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	18.0
Installed capacity savings (M$)		4.1	8.2	12.3	16.4	20.5	24.6	28.7	32.7	36.8	40.9
Carbon dioxide reduction (10^6 kg)		10	20	29	39	49	59	69	78	88	98
Scenario D											
Electricity savings (GW h)		4	14	28	48	73	103	138	178	224	274
Cost savings (M$)		0.4	1.2	2.4	4.1	6.2	8.7	11.7	15.1	18.9	23.2
Installed capacity savings (M$)		0.8	2.6	5.4	9.2	14.0	19.8	26.6	34.3	43.1	52.9
Carbon dioxide reduction (10^6 kg)		2	6	13	22	34	47	64	82	103	127
Scenario E											
Electricity savings (GW h)		2	7	14	24	36	51	69	89	112	137
Cost savings (M$)		0.2	0.6	1.2	2.0	3.1	4.4	5.8	7.5	9.5	11.6
Installed capacity savings (M$)		0.4	1.3	2.7	4.6	7.0	9.9	13.3	17.2	21.5	26.4
Carbon dioxide reduction (10^6 kg)		1	3	7	11	17	24	32	41	52	63

Table 6
Fuel savings and environmental impacts by implementing energy efficiency strategies in boilers.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Scenario A	39500	40421	41343	42264	43185	44107	45028	45949	46870	47792	48713
Scenario B											
Fuel savings (TJ)		511	1023	1534	2046	2557	3069	3580	4092	4603	5115
Cost savings (M$)		7.4	14.7	22.1	29.4	36.8	44.1	51.5	58.9	66.2	73.6
Installed capacity savings (M$)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon dioxide reduction (10^6 kg)		37	75	112	149	187	224	261	299	336	373
Scenario C											
Fuel savings (TJ)		256	511	767	1023	1279	1534	1790	2046	2302	2557
Cost savings (M$)		3.7	7.4	11.0	14.7	18.4	22.1	25.8	29.4	33.1	36.8
Installed capacity savings (M$)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon dioxide reduction (10^6 kg)		19	37	56	75	93	112	131	149	168	187
Scenario D											
Fuel savings (TJ)		51	122	211	321	449	597	764	951	1157	1382
Cost savings (M$)		0.7	1.7	3.0	4.6	6.5	8.6	11.0	13.7	16.6	19.9
Installed capacity savings (M$)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon dioxide reduction (10^6 kg)		4	9	15	23	33	44	56	69	84	101
Scenario E											
Fuel savings (TJ)		26	61	106	160	225	299	382	475	578	691
Cost savings (M$)		0.4	0.9	1.5	2.3	3.2	4.3	5.5	6.8	8.3	9.9
Installed capacity savings (M$)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon dioxide reduction (10^6 kg)		2	4	8	12	16	22	28	35	42	50

pipes of visited facilities have been found either un-insulated or poorly insulated.

(c) Repair steam leaks: steam leaks in live steam lines and condensate return lines should be repaired on a regular basis. Repairing steam leaks reduces energy usage for heating of make-up water, reduces water purchase and treatment costs, and contributes to worker safety. It has been found that steam leaks are a common problem for industrial facilities in Jordan.

(d) Repair steam traps: steam traps are used to separate steam from water and non condensable gases. Steam traps can fail in one of two ways: either the trap fails in the closed position and does not allow the passage of condensate, or the trap fails in the open condition and steam is allowed to blow by the trap and is eventually discharged to the atmosphere. The potential savings are due to reduced energy usage for heating of make-up water, and to reduced water purchase and treatment costs. During the site visits, many steam traps have been found working inappropriately.

(e) Pre-heat make up water utilizing solar energy: heating make up water is a major energy consumer in industrial sector. In most of visited facilities, it has been found that the make up water (that compenstae for steam leak and process steam) enters the boiler at room temperature. It is highly recommended in these situations to install solar water heater to raise the make up water temperature above the room temperature and hence save some energy required for steam generation. Solar water heaters can operate in any climate and their performance varies depending on the amount of solar energy available and the coldness of the water coming into the system. The amount of hot water a solar water heater produces depends on the type and size of the system, the amount of sun available at the site, proper installation, and the tilt angle and orientation of the collectors.

Taking into consideration all above recommendations, it has been estimated that 15%–35% of energy consumption can be saved by implementing and maintaining the different energy saving strategies in boilers in the Jordanian industrial facilities. A conservative figure of 15% will be used in this study. Table 6

Table 7
Energy savings and environmental impacts by implementing efficient energy strategies in motors and boilers.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Scenario A	69989	71732	73475	75218	76962	78705	80448	82191	83934	85678	87421
Scenario B											
Fuel savings (TJ)		913	1825	2738	3651	4563	5476	6389	7302	8214	9127
Cost savings (M$)		11.0	21.9	32.9	43.8	54.8	65.7	76.7	87.7	98.6	109.6
Installed capacity savings (M$)		8.2	16.4	24.6	32.7	40.9	49.1	57.3	65.5	73.7	81.9
Carbon dioxide reduction (10^6 kg)		57	114	171	228	285	342	399	456	513	570
Scenario C											
Fuel savings (TJ)		456	913	1369	1825	2282	2738	3194	3651	4107	4563
Cost savings (M$)		5.5	11.0	16.4	21.9	27.4	32.9	38.3	43.8	49.3	54.8
Installed capacity savings (M$)		4.1	8.2	12.3	16.4	20.5	24.6	28.7	32.7	36.8	40.9
Carbon dioxide reduction (10^6 kg)		28	57	85	114	142	171	199	228	256	285
Scenario D											
Fuel savings (TJ)		91	251	478	773	1136	1567	2067	2634	3269	3972
Cost savings (M$)		4.0	8.5	13.4	18.8	24.6	30.8	37.4	44.5	52.1	60.0
Installed capacity savings (M$)		0.8	2.6	5.4	9.2	14.0	19.8	26.6	34.3	43.1	52.9
Carbon dioxide reduction (10^6 kg)		6	15	28	46	66	91	119	152	188	228
Scenario E											
Fuel savings (TJ)		46	125	239	386	568	784	1033	1317	1634	1986
Cost savings (M$)		0.5	1.5	2.7	4.3	6.3	8.6	11.3	14.4	17.8	21.6
Installed capacity savings (M$)		0.4	1.3	2.7	4.6	7.0	9.9	13.3	17.2	21.5	26.4
Carbon dioxide reduction (10^6 kg)		3	8	14	23	33	46	60	76	94	114

shows fuel savings and environmental impacts by implementing energy efficiency strategies in boilers.

6.3.3. Savings summary

Table 7 summarize predicted future energy and cost savings as well as GHG emissions for different scenarios analyzed in this simulation study, where electricity values in Table 5 were converted into their equivalent final energy, i.e., dividing by the weighted average electricity generation efficiency (38.1%) [22].

As can be seen from Table 7, for scenario A, business as usual, it is obvious that industrial energy consumption would grow by approximately 25% by year 2021 as compared to base year 2011. But when efficient practices are introduced, energy consumption is predicted to rise at a lower rate, reaching 11.9%, 18.4%, 19.2%, and 22.1% for scenarios B, C, D, and E, respectively, for same period. This would yield an estimated annual cost savings of about 21.6 million US$ for the most conservative scenario (E) as shown in Table 7. In addition, the total installed capacity cost savings is estimated to be around 81.9, 40.9, 52.9, and 26.4 million US$ for scenarios B, C, D, and E, respectively, by year 2021 as shown in Table 7. Such reductions would help to postpone a portion of the needed investment for adding new generation units, and thereby lower the long-run marginal cost of electricity generation and expansion in supply side. It is a proven fact that the investment in energy saving is much more cost effective than that for adding the same requested capacity, especially when it comes to low cost measures such as those considered in this study. Equally important is that such actions would also release the scarce capital investment, which is urgently needed for social and economic development in Jordan. Moreover, as can be seen from Table 7, for scenario A, business as usual, the CO_2 emissions would rise by approximately 23.0% by year 2021 as compared to base year 2011. But when efficient practices are introduced, CO_2 emissions are expected to grow at a lower rate. This would yield an estimated annual emission reductions of 570×10^3, 285×10^3, 228×10^3, and 114×10^3 t for scenarios B, C, D, and E, respectively. As stated in the clean development mechanism (CDM) of Kyoto Protocol, these carbon reduction emissions can be considered as a source of wealth generation, in Jordan, since GHG emission has relatively high value in the international market of about 25–30 US$ per ton of GHG reduced, at present.

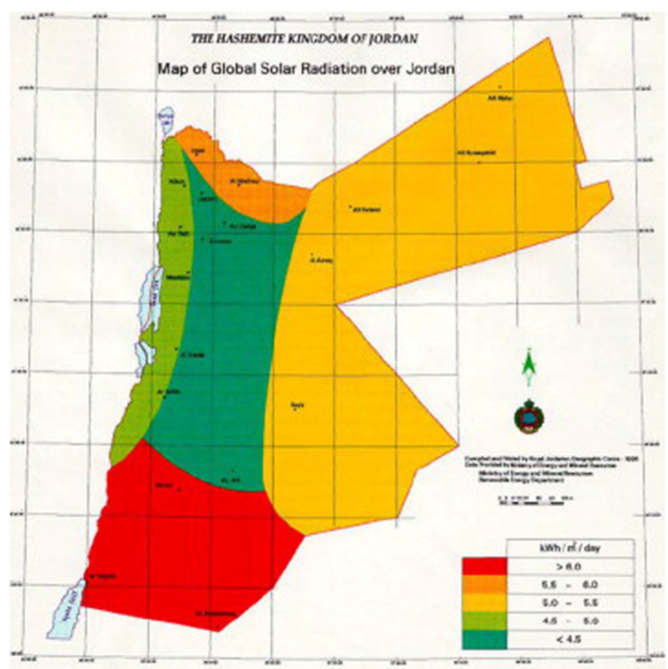

Fig. 4. The solar map of Jordan [24].

6.3.4. Utilization of photovoltaic systems in the Jordanian industrial sector

Jordan has an average daily solar radiation of 5.5 kW h/m^2, and its classified as one of the Sun Belt countries according to the international classification. Jordan extends between latitudes of 29°N and 33°N, and longitudes of 34°E and 39°E. Fig. 4 shows the distribution of the solar regions in Jordan.

The high solar energy amounts enable rewarding economical and environmental invests in the improvement and adaptation of solar energy systems in Jordan. Jordan has more than 300 sunny days a year, providing a sunshine duration of about 3125 h/year.

Comparing with other countries, Jordan, for example, has three times sunshine duration more than Germany. This means that the utilization of photovoltaic in Jordan is feasible if feed-in-tariff law is issued and applied [23].

Among several available technologies, solar photovoltaic (PV) is the most promising one in Jordan. PV technology converts sunlight into direct current (DC) electricity. The PV arrays are connected and synchronized to the grid using an appropriate power conditioning sub-system that converts the DC energy to alternating current (AC) energy synchronized to the grid energy. In recent years, global rapid development in grid-connected PV systems is due to the government-initiated renewable energy programs aiming at the development of renewable energy applications and reduction of greenhouse gas emissions [25]. However, the current regulations in Jordan do not permit grid connected systems but Jordan is in a process to announce these regulations and put them in work. In order to show and emphasize the importance of PV grid connected systems applications in Jordan, Figs. 5 and 6 show the electricity savings and avoided CO_2 emissions for three scenarios:

(a) Scenario 1: All industrial electricity consumptions will be generated totally by PV grid connected systems by year 2021.
(b) Scenario 2: Fifty percent (50%) of industrial electricity consumptions will be generated by PV grid connected systems by year 2021.
(c) Scenario 3: Twenty percent (20%) of industrial electricity consumptions will be generated by PV grid connected systems by year 2021.

As clearly can be seen from these figures, significant benefits in terms of electricity savings and CO_2 emissions reductions can be achieved by implementing PV grid connected systems in the Jordanian industrial sector.

7. Implications and recommendations for national energy policy makers

More recently, Jordan witnessed impressive developments in the commercial and services sectors, which do not consume significant amounts of energy but contribute significantly to generating wealth in the country: the economy could now grow without consuming more energy. Sustainable economic growth should not lead to an increased rate of energy consumption. Energy efficiency should be promoted on the highest decision-making level in order to meet long-term energy demands and a

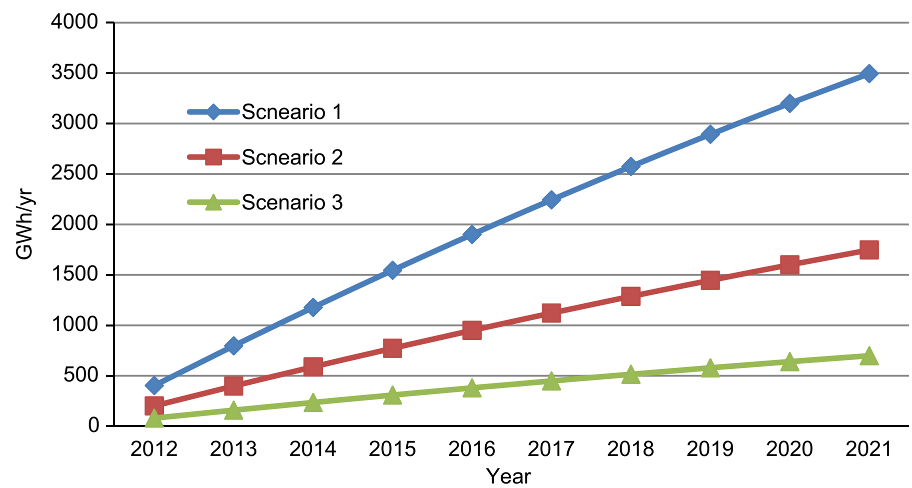

Fig. 5. Electricity savings by implementing PV grid-connected systems in Jordanian industrial sector.

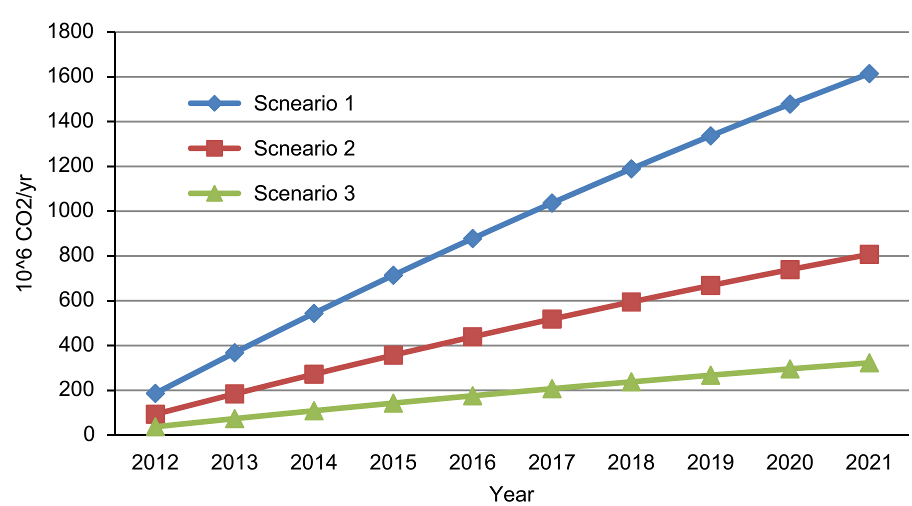

Fig. 6. CO_2 emissions reductions by implementing PV grid-connected systems in Jordanian industrial sector.

comprehensive energy conservation strategy must be established as a main element in the national energy plan. This must take into account the fuel mix and technologies being employed in the different economic sectors. It should include periodic auditing-programs, create incentives to encourage energy conservation, establish an energy-data bank, introduce technical training and public awareness programs, and encourage private-sector participation to invest in energy-thrift and efficient-energy programs where their economics are attractive especially in the transportation sector. However, since the employment of more efficient energy technologies can alter favorably the national energy demand profile, benefit industries and individual consumer's budgets and also contribute towards a cleaner environment, it would be wise that concerned governmental institutions introduce a package of highly-efficient appliances, cars, equipment and machinery as part of electrical-connection or fuel-supply agreements for new or targeted customers. On the other hand, it is deemed that promoting energy efficiency will help in creating new job opportunities and specialized energy industries and services.

Finally, the government of Jordan has acknowledged in its final energy master plan the desire for improving energy efficiency in all sectors and reducing energy intensity, which is considered as first step towards correcting the prevailed situation during last two decades. However, this will not work alone without introducing proper mechanisms, legal and financial frame works. Successful implementation of most of energy efficiency programs, that are viable for the case of Jordanian market, requires both the intention and support from the government as well as understanding and participation of energy suppliers and consumers. But scarce national sources of funding for energy management and environmental protection projects and the government's zero budget allocated for advocating wise energy-management programs are major barriers for promoting energy efficiency in all sectors of the economy. It is extremely important that all governmental institutions should work closely and cooperate in order to avoid having conflicting aims, especially when it comes to energy and environment, e.g., reduce the financial burden of importing oil and gas and supply energy at the least cost to consumers.

8. Conclusions

This study presents a comprehensive analysis of historical, current, and future energy situation of the Jordanian industrial sector. Two empirical models based on multivariate linear regression technique for the electricity and fuel intensities of the Jordanian industrial sector were developed. The developed model identifies main drivers behind electricity and fuel intensities changes from one year to another. The developed model has been proved to be adequate with high values of R^2 and $adj\text{-}R^2$. The significant factors affecting electricity intensity have been found to be the structural effect, electricity prices, capacity utilizations, and number of employees while found to be fuel prices, capacity utilizations and number of employees for the fuel intensity model.

In order to evaluate the current situation, an end use model for the Jordanian industrial sector was developed based on a survey covering most facilities types in Jordan. The survey emphasized that the facilities in Jordan do not employ efficient energy savings strategies such as efficient motors, using VFDs, adjust air-fuel ratio of boilers, insulate bare pipes, etc. For this reason, a mathematical model was developed to evaluate the impact of introducing different energy savings strategies into the Jordanian industrial sector. The analysis demonstrated significant potential energy and environmental benefits as a result of adopting such standards. At worst scenario, it is expected that net savings of approximately 44 M$ per annum, will be achieved by year 2021, if such strategies are adopted in a gradual basis. Consequently, the associated CO_2 emissions reduction will be approximately 190 millions tons per year. The estimation methods and assumptions are clearly described in this paper so that easily can be modified using different sets of data and assumptions to suit the studied case. Having listed the advantages of implementing energy savings strategies in motors and boilers that can lead to electrical and fuel energy conservation, the implementation of such measures is very crucial for the Jordanian industrial sector to reach the desired energy savings. Such study can be considered as the corner stone in achieving national energy savings through implementing efficient measures. Authors believe that this analysis can be applied to other neighboring Arab countries with similar conditions, such as Yemen, Syria, Lebanon and the Palestinian Authority; this is left as a recommendation for future work.

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